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WIND AND TEMPERATURE IN THE ATMOSPHERE BETWEEN 30 AND 80 KM

by

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I. INTRODUCTION

Recent measurements and estimates of the infrared radiational environment of the thermistor have been employed with a more complete form of the temperature error equation. This has resulted in more reliable values of the correction factor which should be applied to rocketsonde temperature measurements. The technique, assumptions and results of this analysis are given in Section II-A of this report. Considering the compressional-frictional heating and radiational environment to which the thermistor is exposed, it is found that this sensor should give remarkably accurate information at heights below approximately 58 km (190,000 feet). Above this level, a correction factor should be applied and appropriate values are given in table 2. Because of the assumptions employed, not only in the derivation of the equations, but also in the specification of the thermistor environment, the correction factors lose their reliability above approximately 65 km. Additional work next quarter is expected to raise this level to perhaps 70 km.

A qualitative discussion of the current research and potential applications of the ARCAS parachute fall speed data is given in Section II-B. Root-mean-square curve fitting techniques are being used on each seasonal collection of data from White Sands Missile Range. Besides yielding a more precise determination of the parachute fall speed, which is necessary for sensor error estimates, it is also hoped that information on the seasonal variation of atmospheric density may be obtained.

Research in rocketsonde data analysis and interpretation has followed two lines of approach during the past quarter. A statistical analysis of rocket winds and temperatures at White Sands Missile Range and the Pacific Missile Range has been completed for the summer 1961 data. Comparisons have been made between these results and the results obtained for the summer of 1960. This study is reported on in Section III of this report. In addition, work has begun in synoptic analysis utilizing the rocket data. Preliminary results of this investigation will be given in the ninth Quarterly Technical Report.

Plans for research during the next quarter are given in Section IV.

II. SENSOR ACCURACY AND REPONSE

A. A Re-evaluation of the Combined Compressional Heating and Radiation Error.

1. General Statement of the Problem

In an earlier report[1] an attempt was made to combine the compressional heating and radiation temperature measurement errors experienced by the rocketsonde thermistor. This combination was achieved by direct addition of the two errors. It was pointed out at the time[1, p. 13] that this addition is permissible only when the two errors were independent of one another; a condition which is never satisfied entirely, but nearly satisfied when the individual errors are small (on the order of 5°C or less). It is the purpose of the current report to provide a more complete and precise determination of this combined error.

2. Fundamental Theory, Assumptions, and Equations

The following symbols will be used in this development:

T_{fe}	temperature of the far or undisturbed atmospheric environment of the thermistor, given approximately by the 1959 ARDC standard atmosphere
T_{ne}	temperature of the near atmospheric environment of the thermistor, given by an algebraic sum of T_{fe} and the temperature rise resulting from compressional-frictional heating effects
a	solar absorptivity of the thermistor
A	surface area of the thermistor
λ	time constant of the thermistor
C	heat capacity of the thermistor
J	flux of short wave (solar) radiation reaching the thermistor

T_{be}	effective blackbody radiating temperature of the environment below the thermistor
T_{ae}	effective blackbody radiating temperature of the atmospheric and space environment above the thermistor
T_{ai}	effective blackbody radiating temperature of the instrument package above the thermistor
σ	Stefan-Boltzmann constant
T	temperature of the thermistor
t	time
$\frac{d}{dt}$	time differential operator (total derivative)
Q	heat transferred by radiation
H	heat transferred by convection
V	ventilation speed of the thermistor, assumed equivalent to the fall speed of the parachute
c_p	specific heat capacity of air at constant pressure

If it is assumed that radiation and convection are the only heat transfer processes of importance for the temperature sensor, we may express the general heat transfer equation for the bead thermistor as

$$C(dT/dt) = Q + H \tag{1}$$

The thermistor is attempting to reach convective equilibrium with its near environment, thus the convective heat transfer term may be expressed as

$$H = (T_{ne} - T)(C/\lambda) \tag{2}$$

The heat transferred by radiation will be considered as composed of direct and indirect solar radiation, infrared radiation from the environment below and above the thermistor, and infrared radiation from the element. The long wave radiation from the environment above the sensor will come in part from the instrument package with the remainder from the atmospheric and space environment.

The ARCAS instrument package subtends an angle of approximately 54° from the center of the thermistor. One is thus able to determine that approximately 12% of the upper half of the thermistor is exposed to infrared radiation from the instrument package, while the remaining 88% is exposed to long wave radiation from the atmosphere and space. If we assume that the sensing element is a blackbody absorber and emitter of infrared radiation, we may write

$$Q = \frac{JAa}{4} + \sigma A(0.5\,T_{be}^4 + 0.06\,T_{ai}^4 + 0.44\,T_{ae}^4 - T^4) \qquad (3)$$

Substitution of equations (2) and (3) into (1) gives

$$T = T_{ne} + \frac{\lambda A}{C}\left[0.25\,Ja + \sigma(0.5\,T_{be}^4 + 0.06\,T_{ai}^4 + 0.44\,T_{ae}^4 - T^4)\right] - \lambda(dT/dt) \qquad (4)$$

In the present development, we will ignore the last term on the right in equation (4). To perform a complete quantitative development with all terms in equation (4) would necessitate specifying initial conditions for T and an initial height for the sounding. This would introduce the additional problem of nose-cone heating, which we would prefer not to consider at the present time. We might further rationalize by saying that rough calculations

show the magnitude of the last term in equation (4) to be quite small below approximately 62 kilometers. Above this level, its neglect becomes somewhat more serious; however, if we use

$$T = T_{nc} + \frac{\lambda A}{C}\left[0.25\ Ja + \sigma(0.5\,T_{be}^{4} + 0.06\,T_{ai}^{4} + 0.44\,T_{ae}^{4} - T^{4})\right] \quad (5)$$

we will at least have a good first order approximation for the temperature of the thermistor when exposed to a convective and radiational environment as given by equations (2) and (3).

Physically, the neglect of the last term in equation (4) implies that the thermistor has come into equilibrium with its radiational and convective environment. As long as the heat transfer environment remains the same, the temperature error will be constant. It is this error which we will compute in the current study using equation (5). In reality, however, the heat transfer environment is changing as the instrument falls through the atmosphere, thus giving a variable temperature error. Consequently, the temperature of the thermistor is not constant, but changing with time during its descent (except for an extremely unlikely combination of circumstances). The last term in equation (4) takes into account the effect of a variable thermistor temperature on the resulting temperature error. This complication will be considered next quarter.

For the thermistor used in the ARCAS rocketsonde, many of the terms in equation (5) are fixed constants or known functions of height; among these are λ, C, A and σ. Solar flux will be assumed constant with height

in the 20 to 80 km interval. A value of 0.042 cal/cm^2/sec will be used. This is 25 per cent larger than the solar constant and is intended to account for atmospheric and terrestrial reflection and scattering.

Values for the effective blackbody radiation temperature of the natural environment above and below the thermistor are obtained by smoothing and extrapolating data given by Aagard.[3] The specification of the effective radiation temperature of the instrument package is rather difficult. It seems reasonable to assume that, because of the large mass of the package, its thermal lag would be extremely large, especially in the upper portion of the height interval under consideration. The values shown in Table 1 are, therefore, thought to be quite reasonable, even though subjective.

The temperature of the near environment is obtained by taking the atmospheric temperature at a given level and adding to it a correction for compressional and frictional heating. According to Middleton[2, p. 237] the temperature rise experienced by a thermometer exposed to high speed airflow will be given by

$$\Delta T = \alpha \frac{V^2}{2c_p} \tag{6}$$

where α is a proportionality constant which is determined experimentally for a particular type of thermometer. Middleton states that this factor usually lies in the range of 0.6 to 0.85. We will arbitrarily use a value of 0.8. The temperature of the near environment will then be given by

$$T_{ne} = T_{fe} + \Delta T = T_{fe} + 0.4 \frac{V^2}{c_p} \tag{7}$$

Table 1

Values of Height Dependent Parameters Used in the Solution of Equations (5) and (7)

Height (km)	T_{fe} (°K)	V (m/sec)	T_{ne} (°K)	λ (sec)	T_{be} (°K)	T_{ae} (°K)	T_{ai} (°K)
20	216.7	6	216.7	.57	253	111	219
23	216.7	8	216.7	.59	250	103	220
26	221.3	10	221.3	.62	248	96	230
29	230.6	12	230.7	.66	247	90	243
32	239.9	16	240.0	.72	247	85	254
35	249.1	21	249.3	.80	246	80	265
38	258.4	26	258.7	.90	246	76	275
41	267.7	34	268.2	1.05	246	72	280
44	277.0	42	277.7	1.24	245	68	283
47	282.7	53	283.8	1.54	245	64	284
50	282.7	62	284.2	1.93	245	60	284
53	282.7	80	285.3	2.5	245	57	285
56	275.3	99	279.2	3.3	244	54	286
59	262.5	125	268.7	4.5	244	51	287
62	249.5	148	258.3	6.4	244	48	288
65	236.6	176	249.0	9.1	244	45	288
68	223.6	209	241.0	13.7	244	42	288
71	210.8	246	235.0	20.4	243	39	288
74	197.8	291	231.6	31	243	36	288
77	184.9	344	232.3	47.	243	33	288
80	172.0	398	235.4	70.	243	30	288

The ventilation speed is determined from a second degree polynomial fit by root-mean-square techniques to observational data (see Section IIB of this report). The polynomial is fit to data in the height interval 30 to 60 km (approximately) and used for extrapolation down to 20 km and up to 80 km.

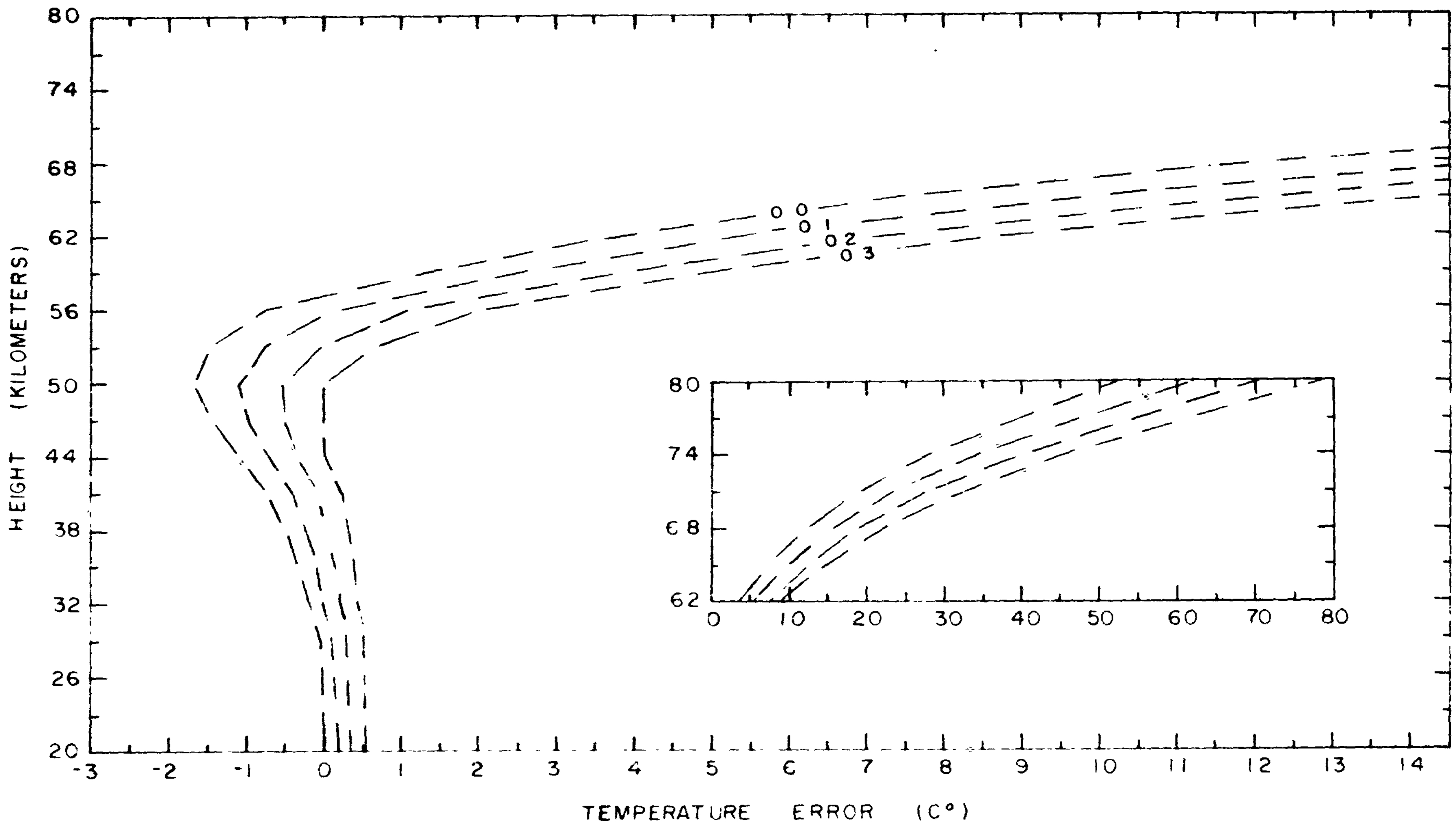
Values for the various height dependent parameters are given in Table 1.

Equation (5) may be solved for the temperature of the sensing element as a function of height and solar absorptivity. From this, the temperature error, $T - T_{fe}$, may be easily determined. In order to solve this fourth order polynomial in T, an iterative technique was employed where the first assumed value for T is taken as T_{ne}. The Newton-Raphson method was used and found to be convergent. Iteration was continued until the absolute value of the difference between two successive iterates was less than or equal to 0.01°C. The entire process was programmed for the CDC 1604 computer.

3. Computational Results

The results of the solution of equation (5) are shown in Figure 1. Evaluation of the equilibrium temperature difference between the thermistor and far-environment was performed in 3 km increments from 20 km to 80 km and for solar absorptivities of 0.0, 0.05, 0.1, 0.15, 0.2, 0.25 and 0.3. Only curves for 0.0, 0.1, 0.2, and 0.3 are shown in Figure 1; the temperature error associated with the intermediate values can be obtained with sufficient accuracy by linear interpolation.

Several items of interest are apparent in this figure. If we initially stipulate that reasonable accuracy for temperature measurement is



COMBINED COMPRESSIONAL HEATING AND RADIATIVE TEMPERATURE ERROR OF THE ARCAS ROCKETSONDE THERMISTOR

FIG. 1.

$\pm$ 2°C, then we can see that uncorrected temperature data should be "reasonably accurate" up to 56 to 60 km, depending upon the solar absorptivity of the sensor (assuming that it is at least in the interval 0.0 to 0.3). Additionally, only an approximate value for the solar absorptivity is needed since the variation in temperature error with solar absorptivity is fairly small (within $\pm$6°C) up to about 70 km. Any attempt at temperature correction above 70 km would be questionable, not only because of the increasing dependence upon an accurate knowledge of the solar absorptivity, but also because of the increasing importance of the term which was neglected in equation (4). We should be in a position to say more about this in the next quarterly technical report.

The solar absorptivity of the white Krylon coated thermistor is thought to be in the interval 0.1 to 0.2. If we assume that, due to the swinging motion of the parachute, the sensing element will, periodically, be exposed to direct sunlight followed by shade, then the average solar flux reaching the thermistor would undoubtedly be less than the 0.042 cal/cm^2/sec which was used in performing the calculations. We can account for this by considering an "effective solar absorptivity" which is somewhat smaller than the true value. A reasonable choice would seem to be 0.1 for daytime soundings. For nighttime soundings the choice should obviously be 0.0. Table 2 shows the amount which should be added to the observed temperature (to the nearest degree) in order to obtain a temperature which has been corrected for the type of convectional and radiational environment as previously described.

Table 2

Temperature Correction Factor to be Added to Observed Temperature for Daytime and Nighttime Soundings

Height		Daytime (a = 0.1)	Nighttime (a = 0.0)
KM	K-FT	°C	°C
		No correction is necessary below 38 kilometers	
38	124.6	0	+1
41	134.5	0	+1
44	144.3	+1	+1
47	154.1	+1	+1
50	164.0	+1	+2
53	173.8	+1	+1
56	183.7	0	+1
59	193.5	-3	-1
62	203.4	-6	-4
65	213.3	-10	-7
68	223.1	-16	-12
71	233.0	-24	-19

4. Conclusions

One unescapable conclusion from the preceding development is that the thermistor currently used in the Meteorological Rocket Network gives remarkably good information up to approximately 58 km (190,000 feet) during the day and approximately 60 km (197,000 feet) at night. There appears to be little need to apply corrections to data obtained below these heights, provided, of course, that the sensor has been exposed to the atmosphere for several minutes prior to reaching these elevations. The reason for this is to minimize the effects of nose-cone heating during rocket ascent. Since almost all of the temperature data thus far obtained is below 190,000 feet, we may conclude that most of the data currently available can be used without applying any correction factor. One exception to this would be if the fall velocity of the parachute differed significantly from that given in Table 1. These cases are rare.

The temperature error increases quite rapidly at heights above 58 km. At the same time, the reliability of this error determination decreases as a result of previously stated assumptions and unknown variations in the convective and radiational environment at these high levels. Table 2 should provide reasonably accurate correction factors up to 65 km but should be used only to indicate the trend of the error above this height. A more precise specification of the correction factor in the 70 km region should be available for presentation in the next quarterly technical report.

B. Evaluation of the ARCAS Parachute Fall Speed

No attempt will be made in this section to present any of the few quantitative results of this study which have thus far been obtained. Rather, a qualitative description of the work under way will be given with some comments to future efforts on this subject. Certain phases of the research should be completed in time for presentation in the next quarterly technical report.

Research was motivated on this topic as a result of: (a) an accurate knowledge of the fall speed of the parachute is essential in order to calculate compressional heating effects and other response characteristics of the thermistor to changes in its environment, and (b) the fall speed data is, to the author's knowledge, an untapped source of information as far as the structure of the atmosphere is concerned.

The relationship between fall speed and response characteristics should be quite apparent. It has been mentioned in almost every quarterly technical report on this contract, including this one (in Section IIA). No more will be said about it here.

Theoretically, the terminal fall velocity of the parachute should be inversely proportional to the square root of the density. It should be possible, then, according to theory, to compute the atmospheric density on the basis of fall velocity data. This would be extremely valuable, of course, since we would then have independent measurements of density and temperature from which pressure could be computed. Unfortunately, there are reasons why one must be careful in working with data of this nature. Some of these may be listed as:

(1) Vertical motion in the atmosphere would be observed by ground based radar as variations in the fall speed, and thus interpreted as variations in density;

(2) a parachute which is not fully inflated will fall at a considerably faster rate than a fully blossomed chute;

(3) the theoretical constant of proportionality may not agree with the actual value;

(4) instrument, data reduction and data tabulation errors could cause considerable difficulties.

It seems probable that some of these difficulties could be eliminated, or at least minimized, by considering a seasonal average of fall speed, rather than performing computations and interpretations on a daily basis. Items (4) and (1) above are of this category if we assume the errors in (4) are random and the vertical motion at any particular height averaged over a season is zero (or at least very small). Both of these assumptions seem quite reasonable. Most of the streaming parachute data (item 2 above) can be recognized quite easily and eliminated from the analysis in the beginning phase of data reduction. Item (3) should not be too critical, especially if we limit our initial work to the determination of density changes from one season to the next. By considering the ratio of fall velocities, the proportionality constant should cancel out.

With these factors in mind, the height-time interval data given in the first four Meteorological Rocket Network data reports has been tabulated in terms of height change per one minute time interval. In order to perform some linearization of the resulting fall speed versus height information, the natural logarithm of the fall speed was plotted on a scatter diagram for corresponding height. This was done for each season of the year. In general, the points very closely approximated a straight line. Points of obvious discrepancy were

investigated and in most cases were found to be associated with a streaming parachute. In a few other cases, the terminal fall speed had not yet been reached. Only rarely (and most of this is the first group of data) were there some points which were obviously in error, but for no obvious reason.

The data were then punched on cards with the abscissa and ordinates represented by the logarithm of the fall speed and height, respectively. Fall speeds down to 3000 feet per minute were considered. The data for each season were then run with a library program from The University of Texas Computation Center entitled "Least Squares Curve Fitting with Orthogonal Polynomials." [4]

For the first set of data (Summer 1960) curve fitting polynomials of order zero (a constant), one (a straight line), two (a quadratic), and three (a cubic) were determined. The difference between the second and third degree polynomials was extremely small, therefore all succeeding sets of data have been fit by polynomials up through order two. The curve fitting phase of the research should be completed in the next few weeks. A complete presentation of the results along with appropriate analyses will be given in the next quarterly technical report.

III. ROCKETSONDE DATA ANALYSIS AND INTERPRETATION

A. Synoptic Analysis

A thorough investigation of the circulation of the upper atmosphere must be made on several different fronts. The initial study at this Laboratory has been concerned with a statistical climatology of winds and temperatures between 70,000 feet and 200,000 feet. The results of this research, limited as they may be by lack of sufficient information, serve as a basis for future investigations.

A brief summary of the basic conclusions derived from a one-year statistical study of winds and temperatures in the upper atmosphere (70,000 ft - 200,000 ft) at White Sands Missile Range was included in the Seventh Quarterly Technical Report. This report also considered qulitatively such factors as the energy of stratospheric motions, stratospheric turbulence, and advection and vertical motion in the stratosphere. One of the primary goals of this contract will be to consider these processes in more detail and to derive methods by which the rocket data can be best utilized in determining their nature and to what extent they are operative in the stratosphere.

It has been decided, however, that before considering these "dynamic factors" in more detail, another facet of the investigation which has thus far been neglected will be undertaken. This concerns synoptic analysis in the stratosphere. Even though the present rocket network does not lend itself to an investigation of this type, it is believed that for selected situations, where a maximum of data is available, a good start can be made

in this field. The procedure will be to begin with analyses in the lower stratosphere (below 10 mb) where sufficient data is available from radiosonde ascents, and to work upward. Using the lower levels as a reference and utilizing pertinent techniques to fill in the data gaps at the upper levels, it is believed that reasonable results can be attained.

This synoptic study has been initiated during the past quarter. A more complete description of the work, along with some preliminary results,will be included in the Ninth Quarterly Technical Report. The date selected for the initial study was November 10, 1960. On this date rocket winds and temperatures are available at White Sands, Point Mugu, Fort Churchill, and Fort Greely, with additional wind information at Tonopah and Cape Canaveral. Data for the analyses at 10 mb and below is taken from the Northern Hemisphere Data Tabulations published on a daily basis by the United States Weather Bureau. In addition to this, valuable information is being derived from the work of Scherhag and his co-workers at The University of Berlin. The author would like to take this opportunity to acknowledge the cooperation shown by Dr. Scherhag and his organization.

One aspect of the work thus far has concerned the use of the thermal wind equation to determine mean temperature gradients in the middle and upper stratosphere. Mean temperature fields are determined graphically from thickness charts between two pressure levels and compared to the temperature field derived from the wind profile by use of the thermal wind relationship. Results of this investigation will also be included in the Ninth Quarterly Technical Report.

B. Statistical Results

Work has been completed during the past quarter on a statistical study of rocket winds and temperatures at White Sands for the summer of 1961. Results of this study are discussed in Sections III B-1 and III B-2 of this report. The completion of this investigation affords the first opportunity for comparison between mean winds and temperatures for one season in two successive years.

1. Temperature

White Sands was the only network station whose temperature reports were sufficiently plentiful to constitute a reasonable sample from the 1961 summer data. Even so, temperature data were far from abundant, and some bias is undoubtedly introduced by the smallness of the data sample.

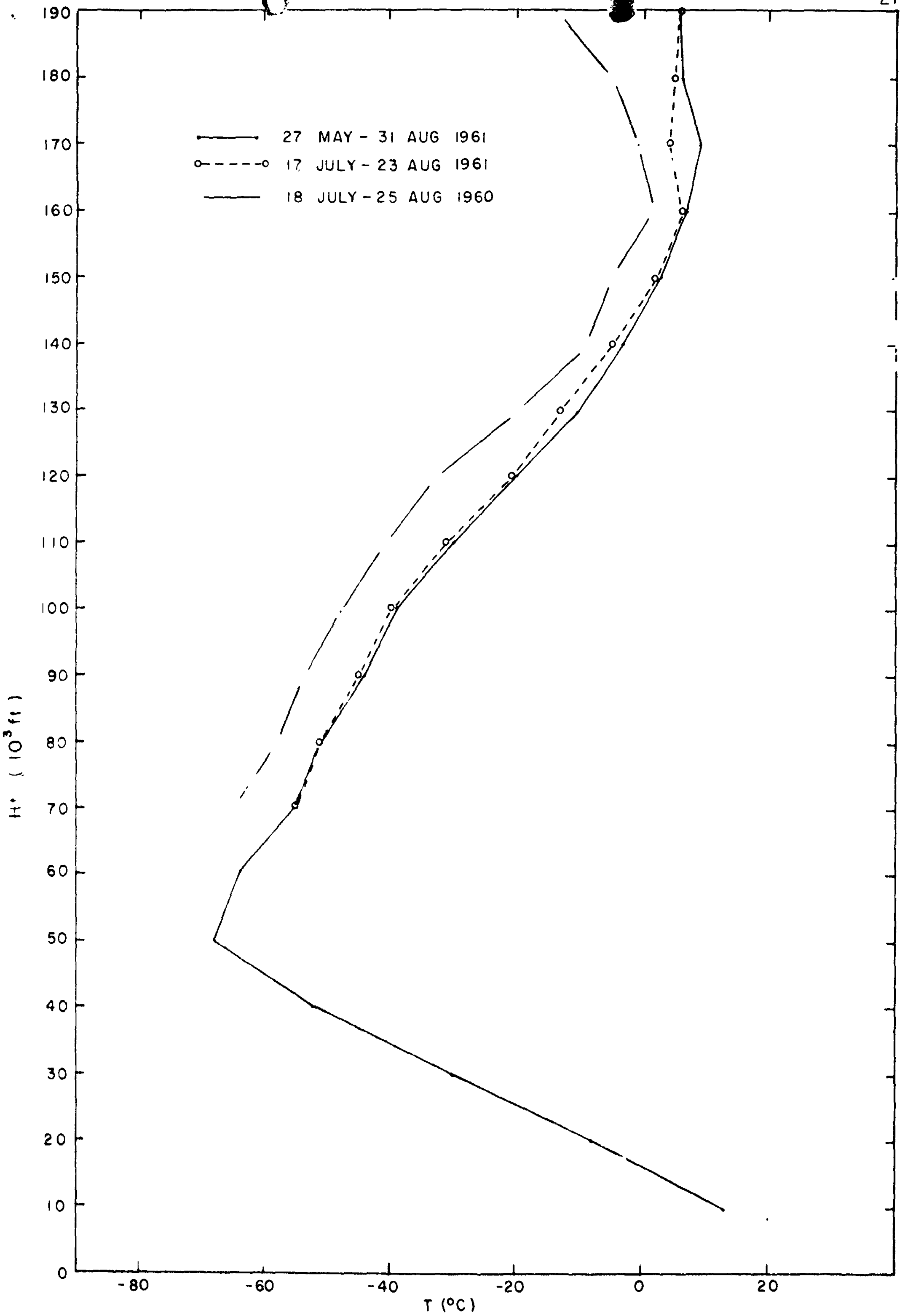
The data report from White Sands for the summer of 1961 differs from that of the previous summer in that the firing period has been extended. The 1960 summer data included only the period from 18 July to 18 August, while the 1961 data included the period from 27 May to 31 August. To enable comparison between the two seasons, two mean temperatures were calculated for the 1961 data. One of these represents the entire three month firing period, while the other is restricted to the period from 17 July to 19 August.

The temperature results are tabulated in table 3 and shown graphically in figure 2. Assuming that the data samples in both years are representative, it is evident that the summer of 1961 was somewhat warmer than the same period in 1960 at all levels above 70,000 ft. The difference

Table 3

Mean Temperatures (°C)
White Sands

Height (10^3 ft)	$\overline{T}$ (27 May-31 Aug 1961)	$\overline{T}$ (17 Jul-23 Aug 1961)	$\overline{T}$ (18 Jul-25 Aug 1960)
70	-55	-55	-65
80	-51	-51	-58
90	-44	-45	-54
100	-39	-40	-48
110	-30	-31	-41
120	-20	-21	-33
130	-10	-13	-20
140	- 3	- 5	- 9
150	+ 3	+ 2	- 5
160	+ 7	+ 6	+ 1
170	+ 9	+ 4	- 1
180	+ 6	+ 5	- 4
190	+ 6	+ 6	-14



MEAN TEMPERATURE, WHITE SANDS

FIG. 2.

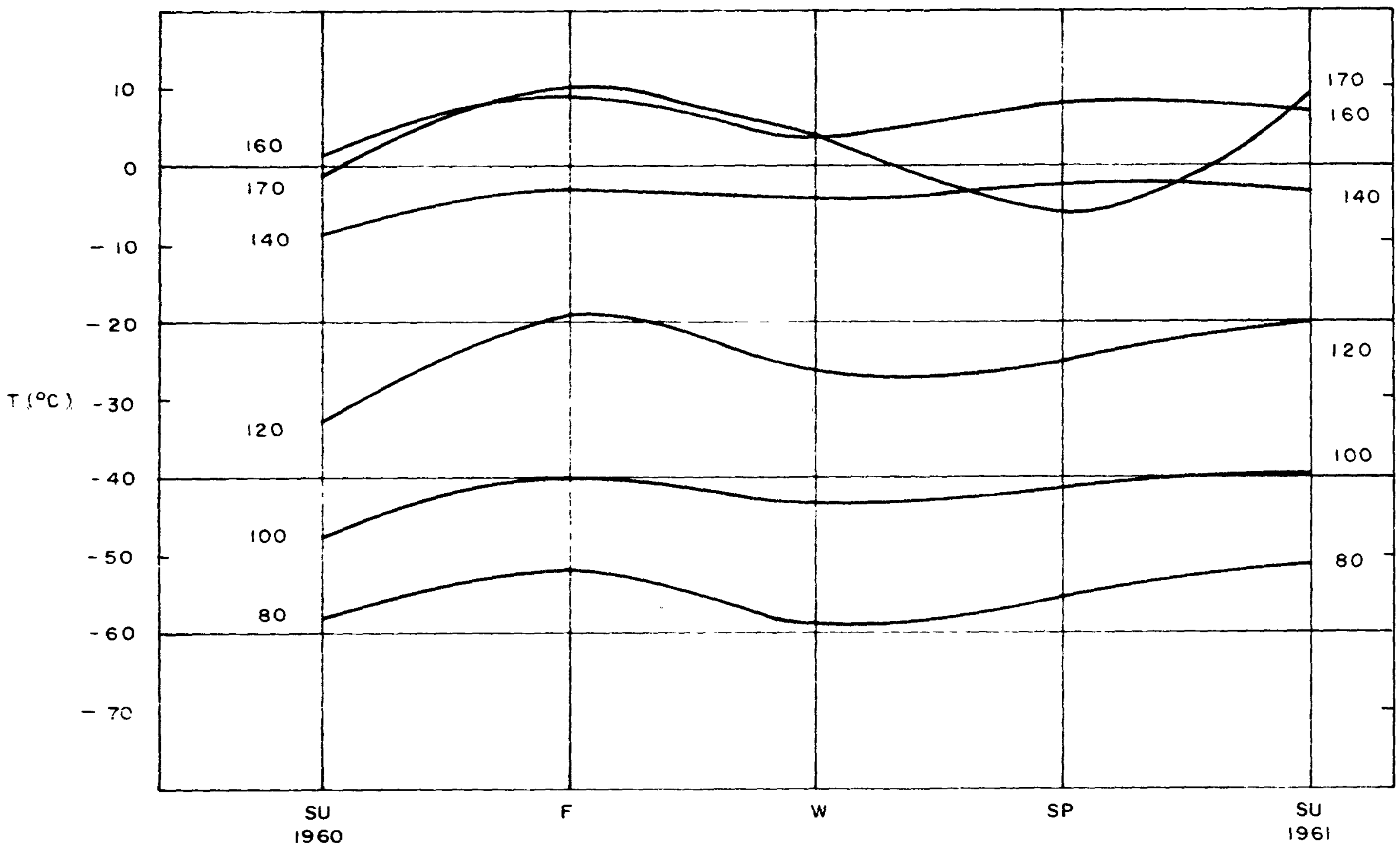
ranges from a maximum of 20 degrees at 190,000 ft to 4 degrees at 140,000 ft. On the average, mean temperatures were some five to ten degrees higher in the summer of 1961 than in the summer of 1960. It is also interesting to note the close correspondence of the two 1961 means. The three-month temperature mean is very close to the one-month mean at all levels. In some instances they are precisely equal.

Figure 3 illustrates mean seasonal temperature changes at six selected altitudes. Here again the differences in the two summer seasons are apparent. As regards temperature, the summer of 1961 was more closely correlated with the fall of 1960 than with the summer of that year. It appears that the smallest seasonal temperature change is found in the vicinity of 140,000 ft.

Figure 4 is a time-height temperature cross section for this same period. This figure, if we exclude the summer of 1960, shows once again the relative constancy of temperature at 140,000 ft. We have no way of knowing, of course, whether the difference in summer mean temperatures is indicative of a relatively cool summer in 1960 or a relatively warm summer in 1961. It is apparent from figures 3 and 4, however, that the summer of 1960 deviates from the mean yearly temperature considerably more than the summer of 1961.

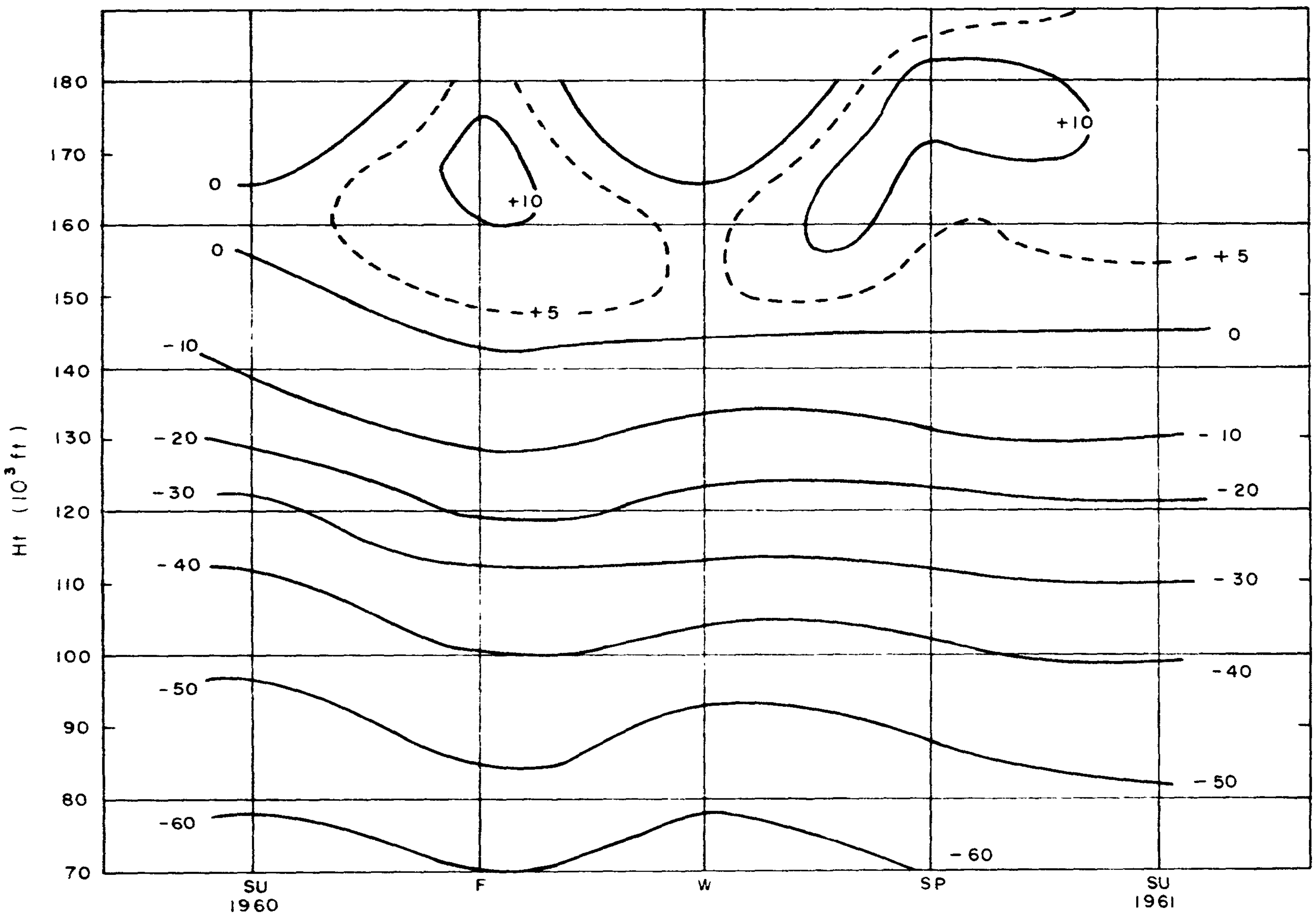
2. Wind

Table 4 is a tabulated summary of wind information derived from the summer 1961 data. The first column gives mean wind speed (ff) in knots at 10,000 ft intervals from 70,000 ft to 200,000 ft. Columns 2 and 3



SEASONAL TEMPERATURE CHANGES
WHITE SANDS, SUMMER 1960 THRU SUMMER 1961

FIG. 3.



TEMPERATURE CROSS SECTION
WHITE SANDS, SUMMER 1960 THRU SUMMER 1961
FIG. 4.

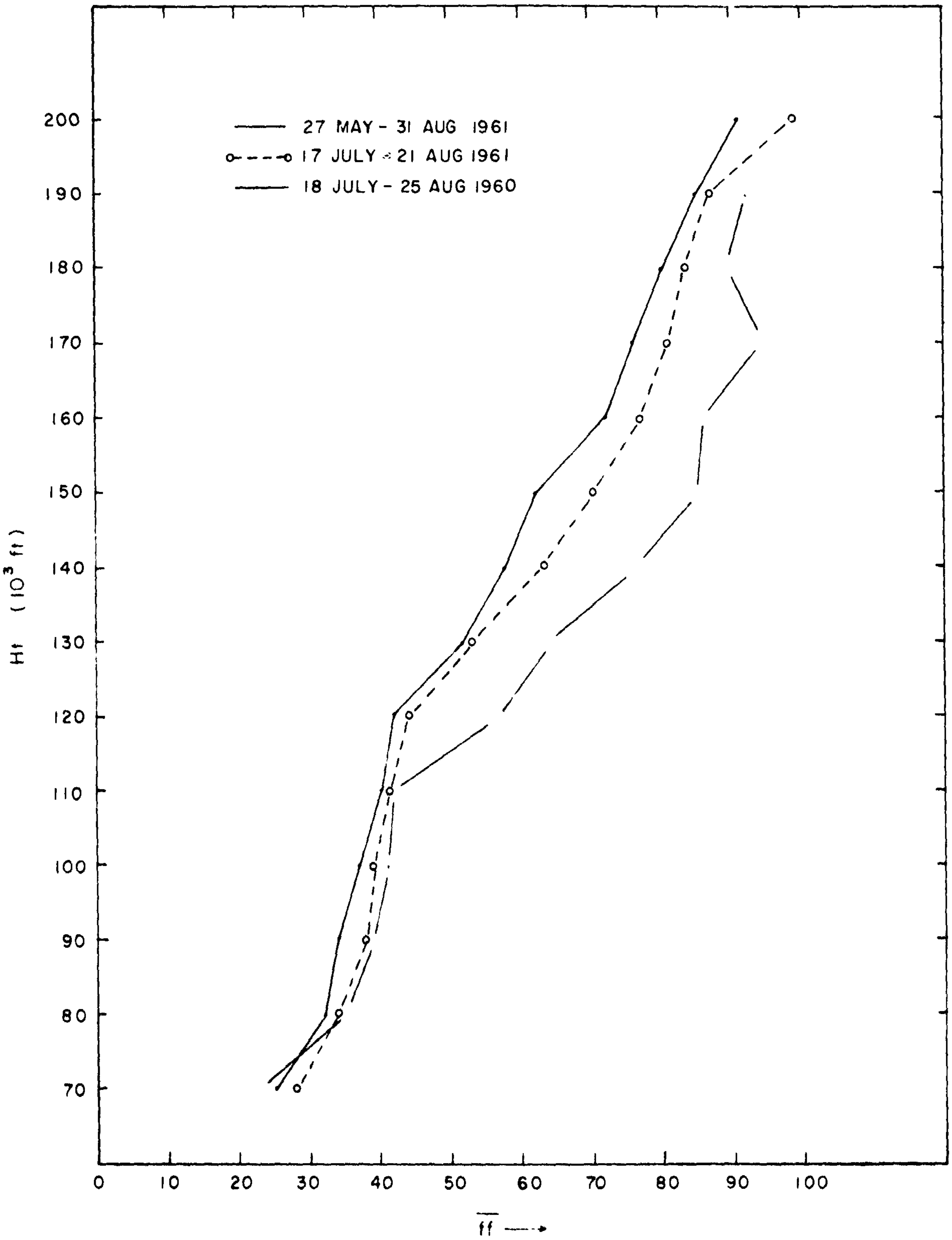
Table 4

Statistical Wind Summary
White Sands - Summer 1961

Ht. (10^3 ft)	ff (knots)	$\lvert\overline{\Delta ff_{24}}\rvert$ knots	$\lvert\overline{\Delta dd_{24}}\rvert$ deg	$\frac{d(\overline{ff})}{dz}\left(\frac{\text{knots}}{10,000\text{ ft}}\right)$	$\frac{d(\overline{dd})}{dz}\left(\frac{\text{deg}}{10,000\text{ ft}}\right)$
70	25	4.4	8.0		
				+7.1	+3.3
80	32	5.1	4.6		
				+2.2	+1.5
90	34	4.5	6.1		
				+4.5	-0.6
100	37	6.9	7.9		
				+2.0	+5.7
110	40	9.3	12.8		
				+2.5	-4.0
120	42	7.2	21.7		
				+4.6	-2.6
130	52	9.9	5.8		
				+8.3	+6.5
140	58	4.2	19.2		
				+5.0	+1.9
150	62	5.6	15.4		
				+8.1	+2.1
160	72	16.2	9.4		
				+7.0	-2.2
170	76	14.2	7.2		
				+5.3	+0.7
180	80	15.5	20.0		
				+7.0	+1.6
190	85	17.5	10.0		
200	91				

give the mean 24 hour changes in wind speed (ff_{24}) and wind direction (dd_{24}). Column 4 represents the vertical shear in wind speed $\frac{d(ff)}{dz}$ within 10,000 ft intervals from 70,000 ft to 190,000 ft. A positive sign in this column corresponds to mean wind speed increasing with height. Column 5 is a tabulation of wind direction changes with height. Here a positive sign indicates a clockwise turning with height, while a negative sign refers to a counterclockwise turning with height. All of the values in Table 4 were derived from data obtained over the entire three-month firing period. In order to compare the two summer periods as before, however, two mean wind speeds were again calculated. Figure 5 shows three plots of mean wind speed versus height. The solid line represents mean wind speed from 27 May to 31 August 1961. The dashed line is mean wind speed from 17 July to 21 August 1961, while the third plot represents mean wind speed from 18 July to 25 August 1960.

Although the two means calculated from the 1961 data correspond relatively well, it does appear that wind speeds were somewhat higher during the period from 17 July to 21 August 1961 as compared to the mean taken over the entire summer. This difference is not nearly as great, however, as the difference between the two successive years. Mean wind speeds for the summer of 1960 are considerably higher than those in 1961. This is especially evident above 110,000 ft. Thus, the summer of 1961 was characterized by relatively high temperatures and low wind speeds when compared to the summer of 1960.



MEAN WIND SPEED
WHITE SANDS
FIG. 5.

Table 5 is a tabulation of wind direction frequency for the period from 27 May to 31 August 1961. Values in the table represent the percentage of time that the winds were contained in each of the octants. Since a wind from 90 degrees represents an east wind, it is evident that all of the summer winds were easterly; no westerly components were reported. The summer season appears to be the most consistent of all of the seasons as regards wind direction. Above 70,000 ft, 100% of the winds fell in the quadrant between 46 degrees and 135 degrees.

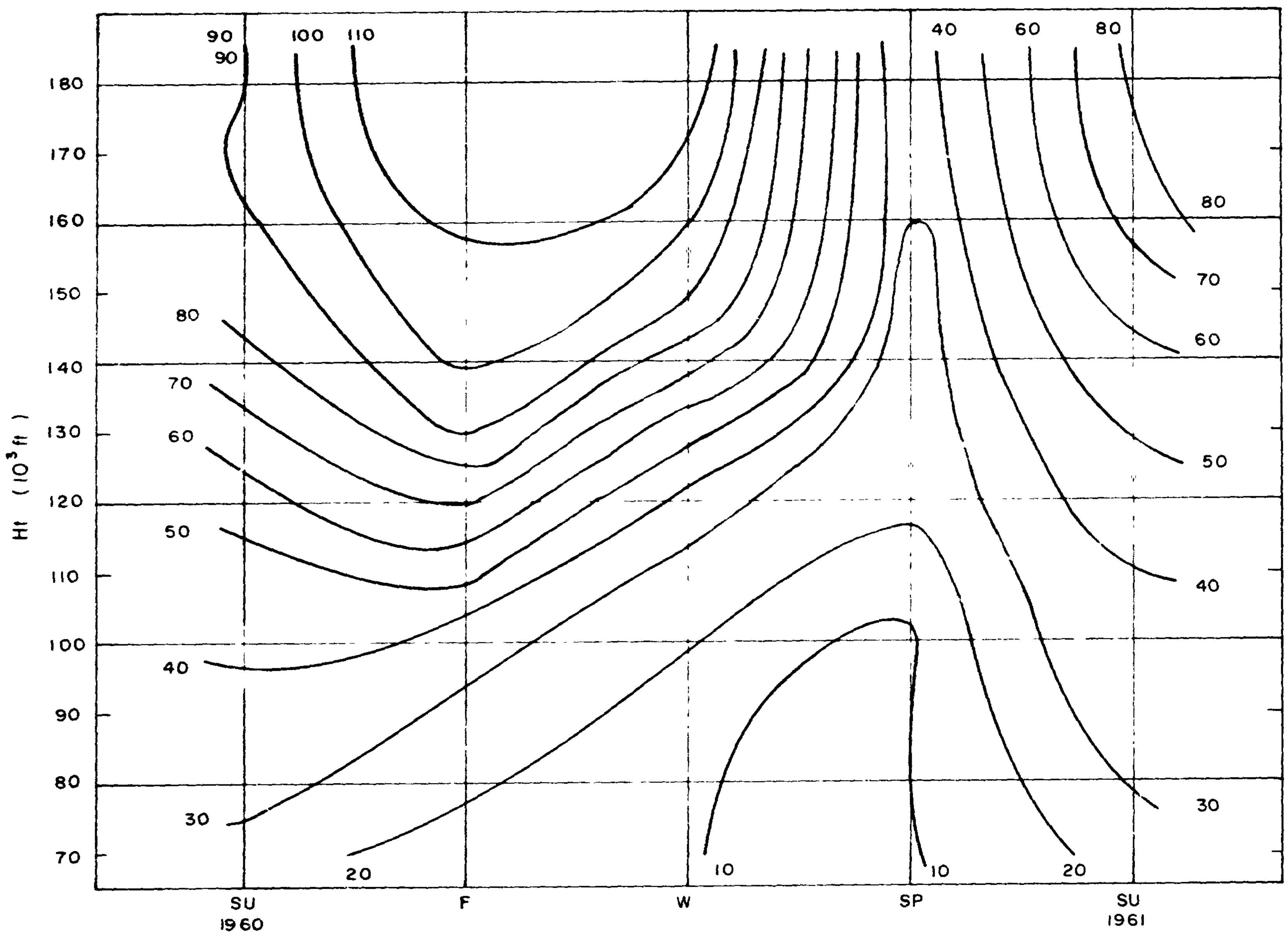
Figure 6 is a mean wind speed (ff) cross section extending from the summer of 1960 through the summer of 1961. Below 100,000 ft, mean wind speeds are relatively light. Minimum wind speeds in this altitude range (70,000 ft - 100,000 ft) are found in the winter and spring while a distinct maximum occurs in the summer. Above 100,000 ft the fall and winter speeds increase rapidly with height. The summer speeds increase also but to a lesser extent, while the spring winds increase in magnitude only slightly between 100,000 ft and 180,000 ft. Consequently, this region is characterized by a strong maximum in the fall and winter and a distinct minimum in the spring.

Figure 6 may be misleading in one respect. Although it appears that the sharpest seasonal change in wind speeds occurs from winter to spring, it must be kept in mind that direction changes have not been taken into consideration in this figure. Reference to the zonal wind cross section given in the Sixth Quarterly Technical Report will show that the sharpest change is actually from the summer easterlies to the strong fall westerlies.

Table 5

Wind Direction Frequency
White Sands - Summer 1961

Ht. (10^3 ft)	0-45	46-90	91-135	136-180	181-225	226-270	271-315	316-360
70	2	65	33	0	0	0	0	0
80	0	52	48	0	0	0	0	0
90	0	43	57	0	0	0	0	0
100	0	48	52	0	0	0	0	0
110	0	40	54	6	0	0	0	0
120	0	50	48	2	0	0	0	0
130	0	58	42	0	0	0	0	0
140	0	44	56	0	0	0	0	0
150	0	35	65	0	0	0	0	0
160	0	8	92	0	0	0	0	0
170	0	24	76	0	0	0	0	0
180	0	38	62	0	0	0	0	0



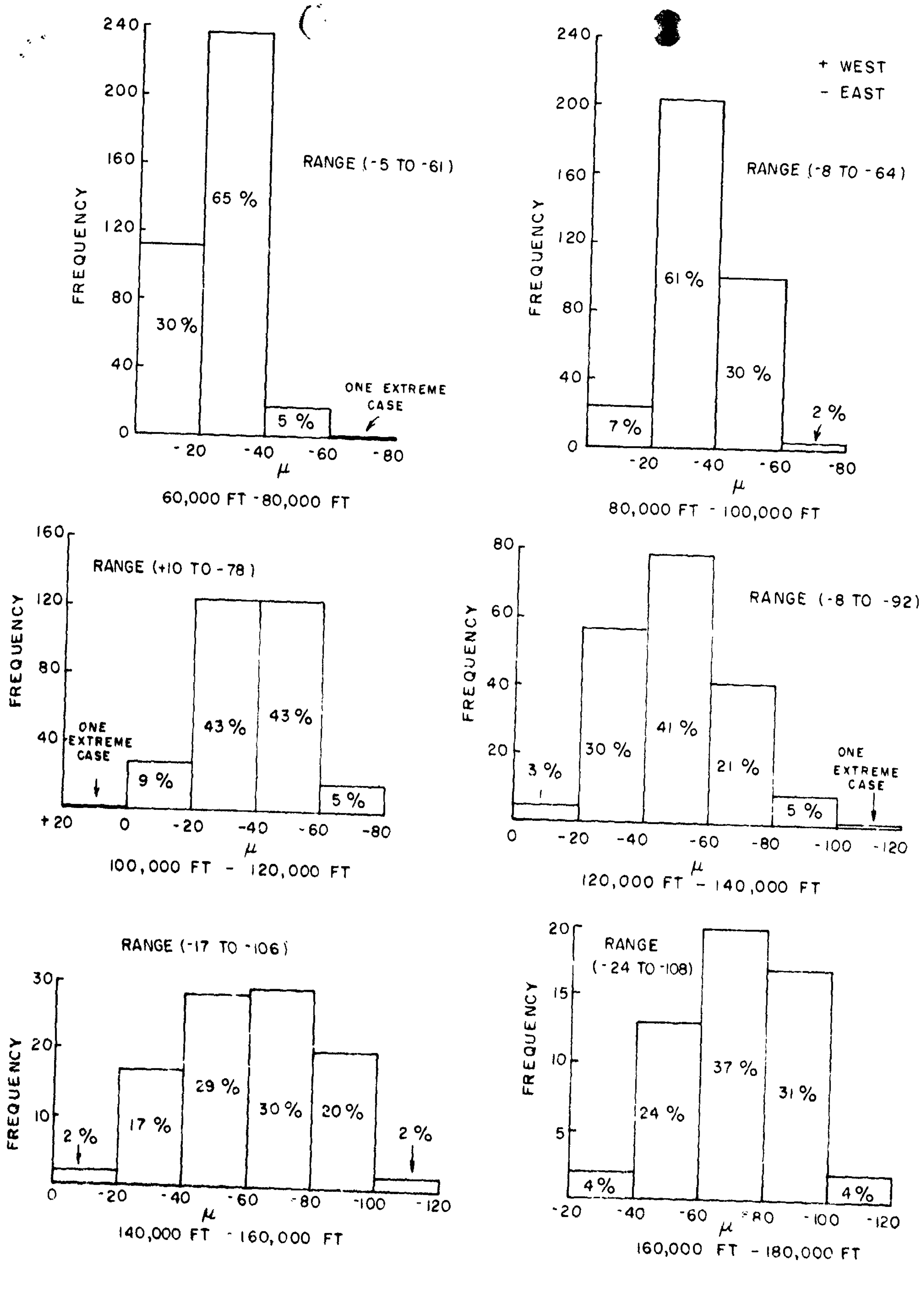
MEAN WIND SPEED CROSS SECTION
WHITE SANDS, SUMMER 1960 THRU SUMMER 1961

FIG. 6.

Figures 7 and 8 are frequency histograms of zonal and meridional wind speed, respectively. In the case of the zonal wind histogram (Figure 7), all of the wind data from 27 May to 31 August 1961 have been considered. The meridional wind histogram (Figure 8) is based only on the period from 17 July to 19 August to allow a more direct comparison between the summers of 1960 and 1961.

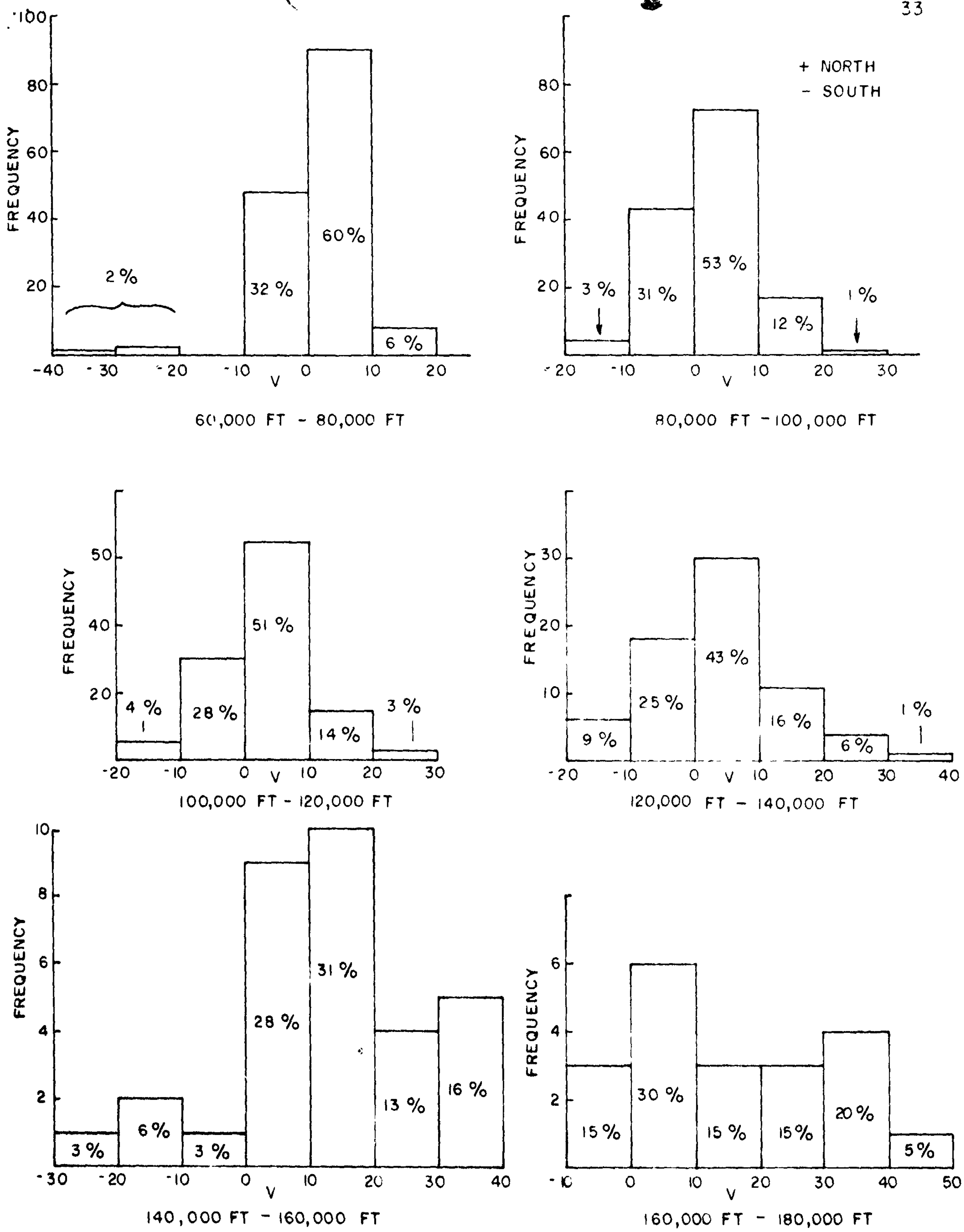
The abscissa in these diagrams represents zonal (or meridional) wind speed in knots, with positive values denoting either a westerly or a southerly wind. The ordinate (frequency) is the number of observations used in deriving the histograms. To obtain the total number of observations on which the diagram is based, one must sum the frequencies associated with each of the speed intervals. For example, there were 236 cases when the zonal wind speed at White Sands between 60,000 ft and 80,000 ft was easterly with a magnitude in the range from 20 to 40 knots. This number of cases represents 65% of the total sample (364 cases) as can be seen from the diagram.

The wind speed intervals were chosen arbitrarily and no attempt was made to fit a normal curve to the data. A comparison of the 1960 and 1961 zonal winds showed that the distribution was very nearly the same except that the 1961 frequency maximum was shifted slightly toward smaller wind speeds. This is hardly noticeable from the histogram, however, since the speeds are grouped in 20 knot intervals, and the frequency maximum in both years was within the same range for each of the six cases. Using the past two years as a reference sample, we can make the following statements concerning the summer zonal wind speeds between 60,000 ft and 180,000 ft.



ZONAL WIND SPEED FREQUENCY HISTOGRAM
WHITE SANDS, 27 MAY - 31 AUG. 1961

FIG. 7.



MERIDIONAL WIND SPEED FREQUENCY HISTOGRAM
WHITE SANDS, 17 JULY - 19 AUG. 1961

FIG. 8.

(1) Essentially 100% of the winds were easterly in this range.

(2) Between 60,000 ft and 80,000 ft, 95% of the zonal wind speeds were less than 40 knots.

(3) Between 80,000 ft and 100,000 ft, 90% of the zonal wind speeds were between 20 and 60 knots.

(4) Between 100,000 ft and 120,000 ft, 85 to 90% of the zonal wind speeds were between 20 and 60 knots.

(5) Between 120,000 ft and 140,000 ft, 90% of the zonal wind speeds were between 20 and 80 knots. In 1961, 70% were below 60 knots while in 1960 only 40% were below 60 knots with nearly 50% between 60 and 80 knots. A closer examination revealed, however, that the majority of these winds in the latter case were in the lower part of the 60 to 80 knot range.

(6) Between 140,000 ft and 160,000 ft, 95% of the zonal wind speeds were between 20 knots and 100 knots with about 80% between 40 knots and 100 knots. In this case, the winds were more equally distributed over a wider range (40 to 100 knots) than in any of the previous cases.

(7) Between 160,000 ft and 180,000 ft, 90% of the zonal wind speeds were between 40 and 100 knots with about 70% in the range from 60 to 80 knots.

In the case of meridional wind speeds, the following conclusions are warranted from a study of both the 1960 and 1961 summer data.

(1) Below 140,000 ft, approximately 30 to 35% of the winds were northerly, while above this level only 10 to 15% were from the north.

(2) In the range from 60,000 ft to 80,000 ft, 90 to 95% of the meridional winds were less than 10 knots in magnitude. About 60% of these were southerly, the remaining 30 to 35% being from the north.

(3) Between 80,000 ft and 100,000 ft, over 95% of the cases were in the range from -10 to 20 (northerly at 10 to southerly at 20). In 1960 about 20% were northerly while in 1961, slightly over 30% were from the north.

(4) Between 100,000 ft and 120,000 ft, 95% of the meridional winds were in the range from -10 to 20. In both 1960 and 1961 about 25% of the cases were northerly while 75% were from the south.

(5) Between 120,000 ft and 140,000 ft, over 90% of the meridional winds were in the range from -20 to 20. In 1960, 40% were northerly while in 1961 about 35% were northerly.

(6) Between 140,000 ft and 160,000 ft, the speed range begins to spread out as was the case with the zonal winds. In this case it is very difficult to find an interval of maximum occurrence. It appears that a weak maximum occurs in the range from 10 to 20 knots which contains about 25 to 30% of the cases. About 75 to 80% of the winds are southerly. Over 90% are in the range from -10 to 40.

(7) Between 160,000 ft and 180,000 ft, about 90% of the winds are in the range from -10 to 30 knots. In 1960, 30% were northerly, while in 1961 only 15% were northerly. In both years about 45 to 50% of the cases were southerly and less than knots in magnitude.

IV. PROGRAM FOR THE NEXT QUARTER

The solution of equation (4) is anticipated with an examination of the importance of the contribution from the last term in this equation. It will be of interest to find not only the height below which the term can be legitimately neglected, but also the sensitivity of the computed temperature correction factors to reasonable variations in this term.

Work will also continue on the ARCAS parachute fall speed analysis with the first quantitative presentation expected for the next quarterly report. This information will be examined in an effort to extract some information on the mean and seasonal density variations in the upper stratosphere. This work will be coordinated with earlier determinations of the seasonal variation of temperature above White Sands Missile Range.

As regards data analysis and interpretation, work will continue in synoptic analysis of the middle and upper stratosphere. Careful consideration will be given to the problem of determining mean temperature fields from the thermal wind relationship as compared to the graphical technique utilizing thickness charts. Preliminary results of this study will be given in the Ninth Quarterly Technical Report.

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